Modifying WWTPs to Achieve Nitrogen Removal

Energy Management Initiative Wave Five

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Organisms and Their Means of Respiration

- Aerobic - use elemental oxygen
- Anoxic - use nitrate (NO_3) or nitrite (NO_2)
- Anaerobic - use other terminal electron acceptors (SO_4 , CO_2) or none at all
- Facultative - two or means of respiration
- Fermentative - no terminal electron acceptor

Nitrification

- Autotrophic
- Aerobic
- Not floc formers

Denitrification

- Heterotrophic
- Anoxic (facultative)

Denitrification

Denitrification is the biological conversion of NO_3-N to more reduced forms:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

Denitrification generally occurs under anoxic conditions and is achieved by facultative heterotrophs

Factors Affecting Denitrification

- **Substrate degradability**
- pH
- **Dissolved oxygen**
- Temperature

Denitrification: Biochemical Reactions

Sewage as carbon source:

$$C_{10}H_{19}O_3N + 10NO_3^- \rightarrow 5N_2 + 10CO_2 + 3H_2O + 10\ OH^- + NH_3$$

Effect of DO on Denitrification Rates

DO Conc, mg/L	Denitrification Rate
0.0	100%
0.1	40%
0.2	20%
0.3	10%
> 0.3	Negligible

Oxygen Savings with Denitrification

For every gram of NO_3-N that is reduced to nitrogen gas, 2.86 grams of oxygen are saved.

Performance of Single-Sludge Denitrification

- Can achieve high N removals (85% to 95%)
- Does not necessarily enhance sludge settleability in final clarifier
- Uses carbon source in influent
- Reduces the energy requirements for BOD removal from the wastewater (2.86 lb O_2 equivalent per lb of NO_3-N removed)
- About one-half of alkalinity required for nitrification is produced in anoxic zone

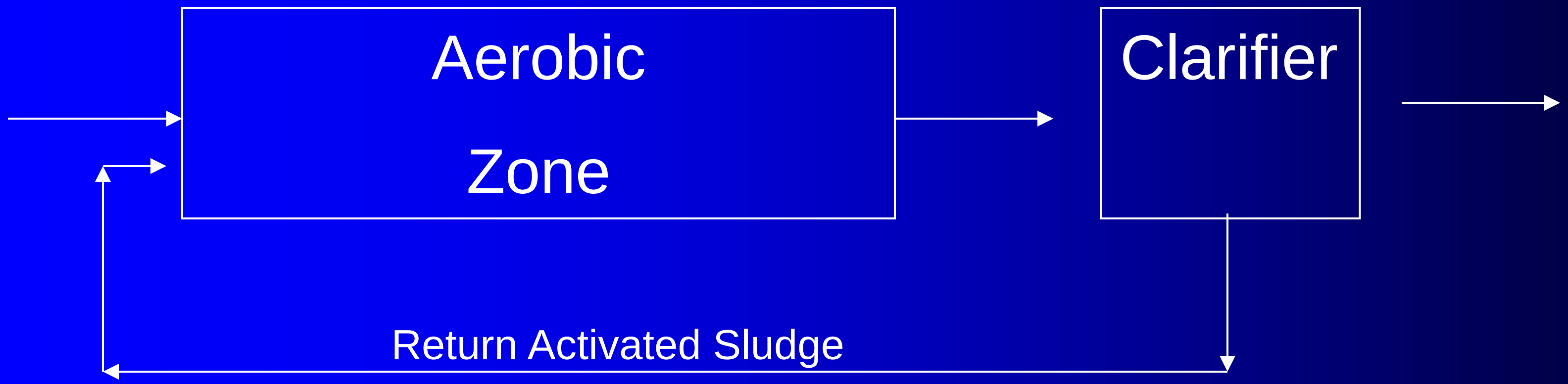
WWTP Changes to Achieve Nitrification-Denitrification

- Modify rectangular aeration basin with baffles to provide anoxic and aerobic zones
- Modify step-feed system to include alternating anoxic and aerobic zones
- Modify oxidation ditch to provide anoxic and aerobic zones
- Modify SBR system to include anoxic and aerobic cycles
- Modify activated sludge operation with on/off aeration cycles to achieve denitrification

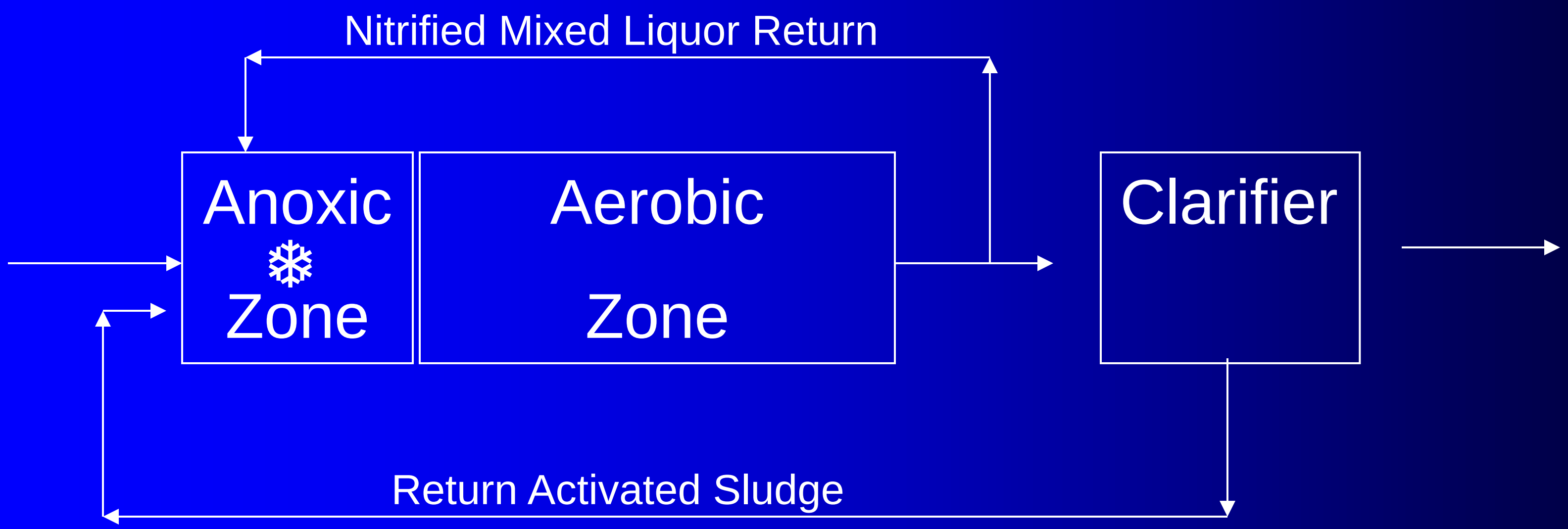
Rectangular Aeration Basin

Modified Rectangular Aeration Basin

Conventional Activated Sludge



Add an Anoxic Zone using Baffle, Mixed Liquor Return, and Mixing



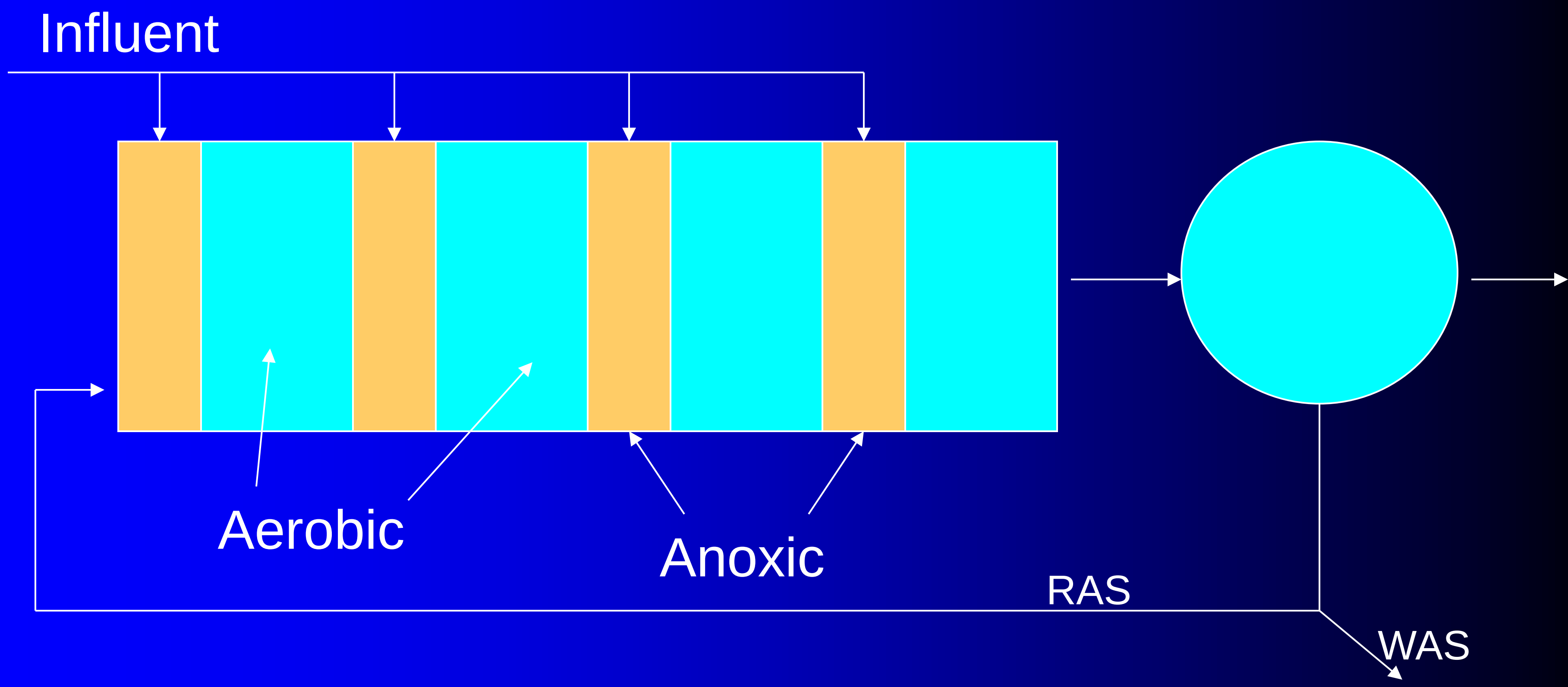
Before and After Effluent Quality

Effluent Quality:

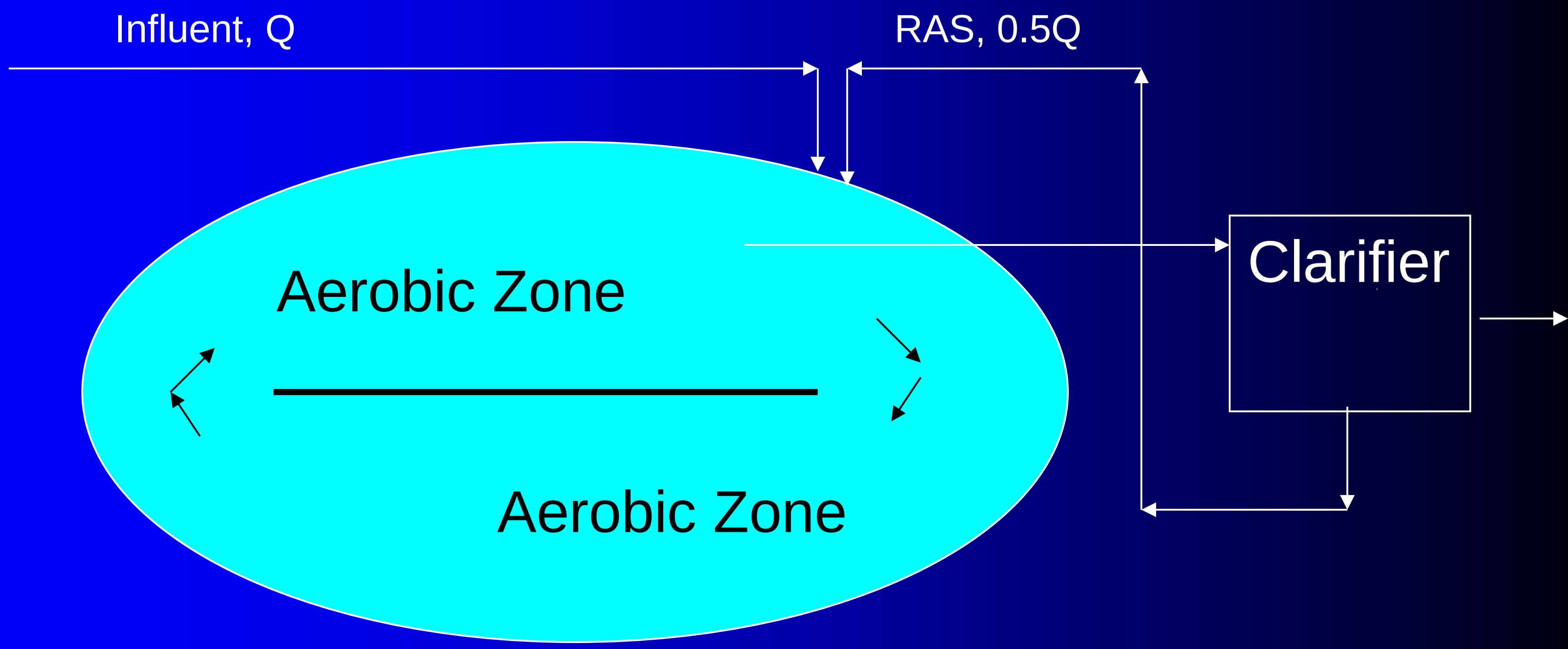
	Before	After
BOD_5	5 - 25 mg/L	5 - 15 mg/L
TSS	10 - 25 mg/L	10 - 20 mg/L
Ammonia-N	1 - 5 mg/L	1 - 2 mg/L
NO_x-N	8 - 15 mg/L	3 - 9 mg/L
Total N	10 - 20 mg/L	5 - 12 mg/L
*SVI	125 - 225	50 - 125

* impacts on mixed liquor at one facility

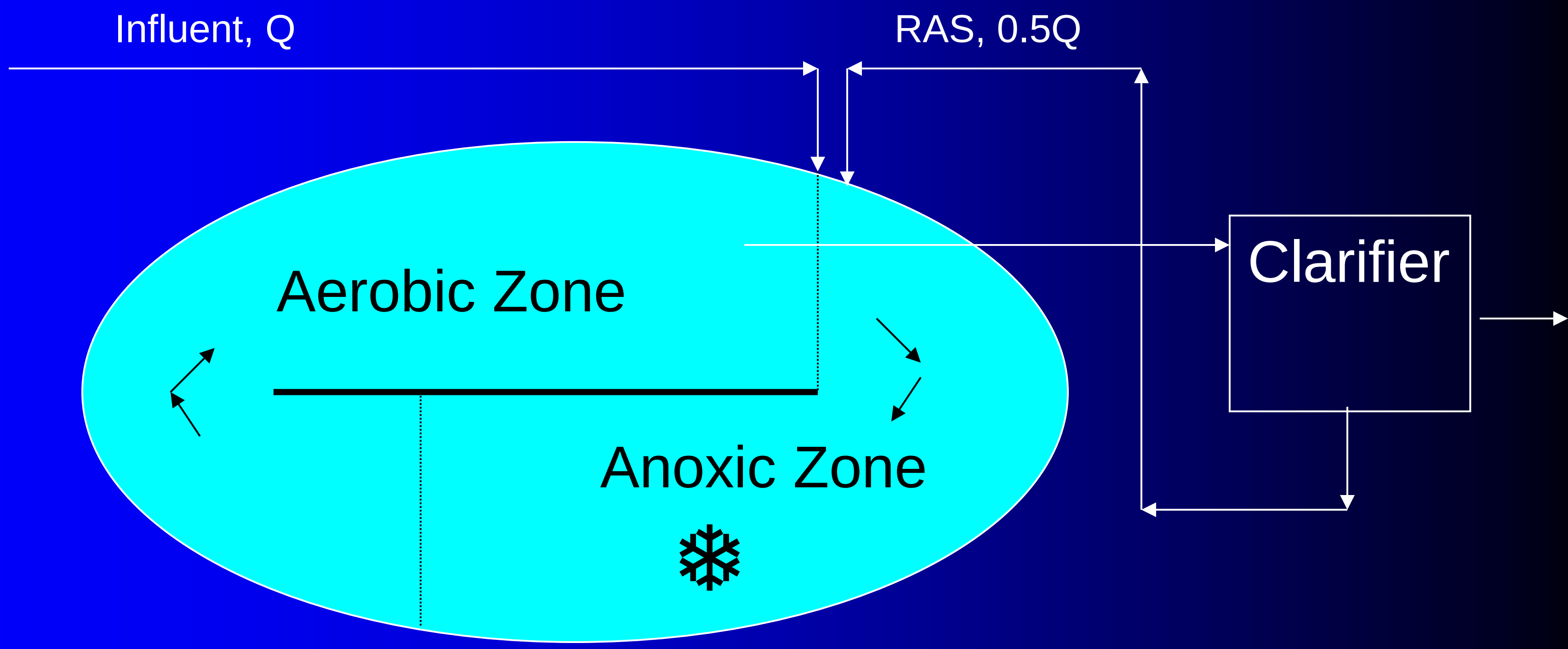
N Removal in Step-Feed Process



Oxidation Ditch Before Modification



Oxidation Ditch After Modification



Nitrogen Removal in SBRs

- Use anoxic and aerobic cycles to effectively remove nitrogen
- Cycles are:
  - Fill (anoxic)
  - React (aerobic/anoxic)
  - Settle
  - Decant

Nitrogen Removal in SBRs

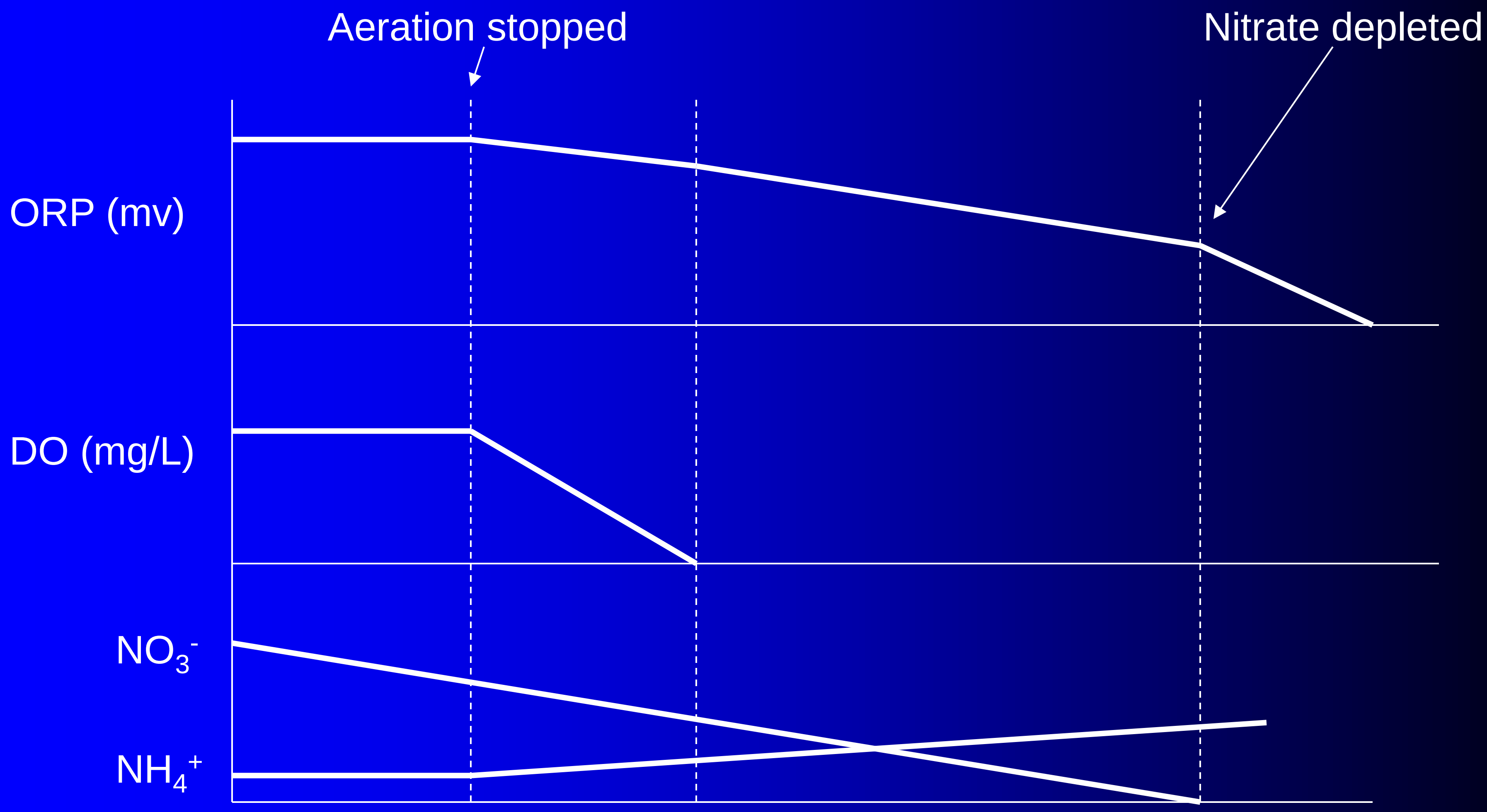
Expected Effluent Quality:

BOD_5	3 - 10 mg/L
TSS	5 - 10 mg/L
Ammonia-N	< 1 mg/L
NO_x-N	3 - 10 mg/L
Total N	5 - 12 mg/L

Intermittent Aeration for N Removal in Activated Sludge

- Cycle time for on/off operation of aerators may vary
- Process control with DO and ORP monitoring
- When aerator is off, must provide mixing
- During off period, aeration tank becomes anoxic reactor, and nitrate is consumed as bacteria degrade BOD
- ORP data are used to terminate off cycle and start aeration

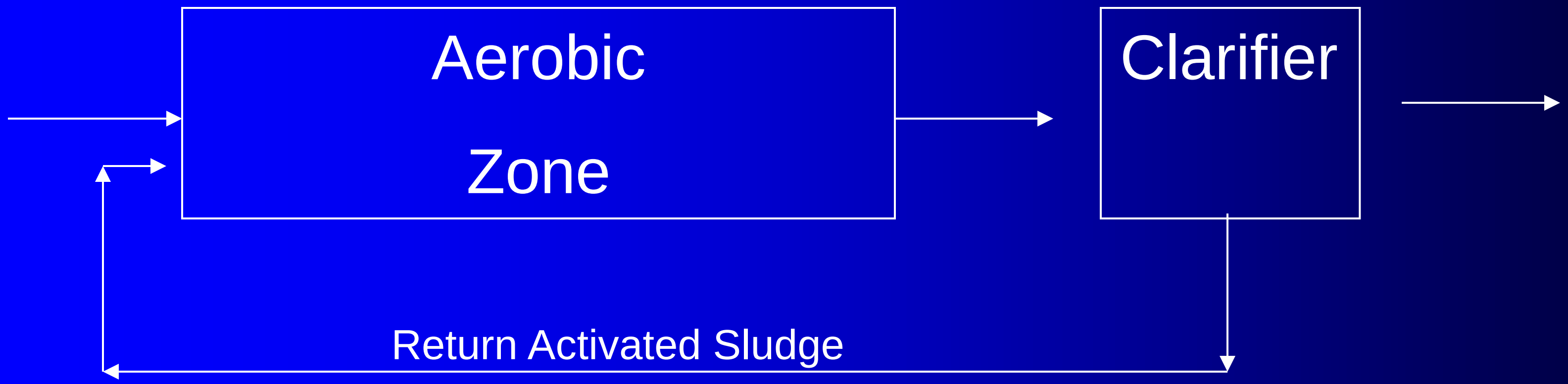
Change in ORP and DO in On/Off Operation



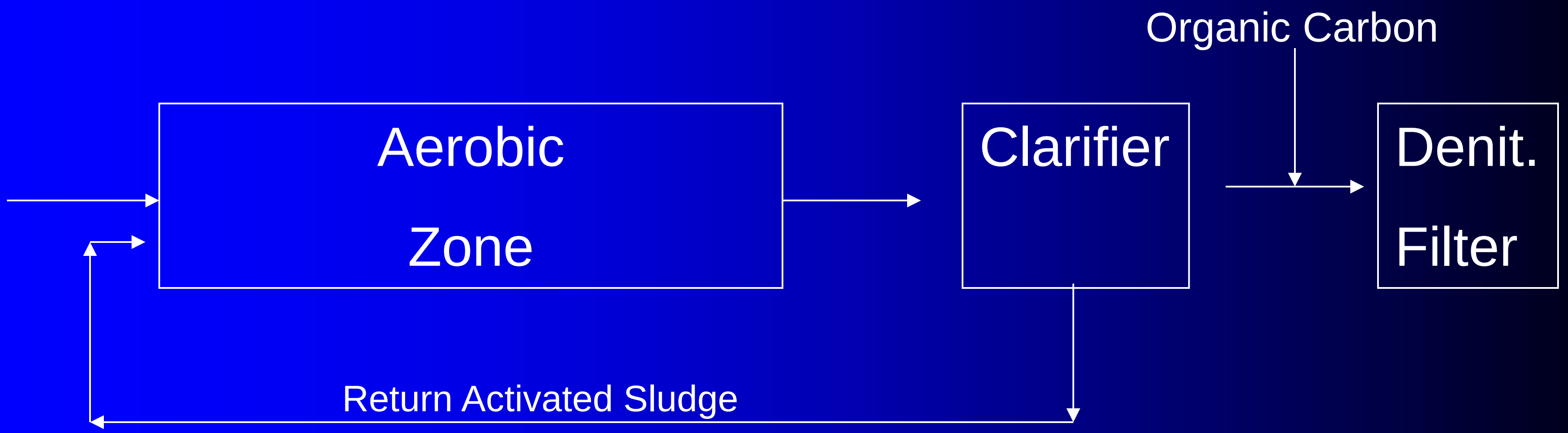
Factors Affecting On/Off Operation

- Oxidation ditch HRT
- Influent flow rate
- TKN and BOD concentrations
- Number of on/off cycles per day
- Ditch MLSS concentration

Conventional Activated Sludge



Add Denitrifying Filter and Carbon Source



Principles in Implementing N Removal

- Consider a wide variety of alternatives
    - adding anoxic zone
    - adding anoxic denitrifying filter
    - adding anoxic moving bed reactor
- Invest in plant-specific waste characterization data
- Engineer and operators should discuss changes
- Tailor to specific plant situation
- Balance risk and cost

Operational Considerations in N Removal

Wastewater Temperature:

- Nitrification capability can be adversely affected by low temperature
- Complete nitrification may be achieved at 9°C
- SRT at 10 °C should be 3 times that at 20 °C
- Operate year-round at SRT needed for cold weather
- Denitrification rates are less affected by low temperatures

Operational Considerations in N Removal

Mixing Requirements:

- Contents of anoxic zone require thorough mixing (40 to 50 hp per mil gal)
- However, mixing must not induce oxygen transfer from atmosphere
- Use propeller mixers or vertical turbine mixers
- Number and placement of mixers are critical
- Follow manufacturer's recommendations

Operational Considerations in N Removal

Process pH Control:

- Each lb of NH_4-N oxidized requires 7.1 lb alk
- Consumption of alkalinity may cause significant pH drop
- May need supplemental alkalinity
- Each lb of NO_3-N reduced produces 3.5 lb alk, which offsets alkalinity destroyed by nitrification

Operational Considerations in N Removal

Return Activated Sludge Rates:

- If system has no internal recycle pumps, one may rely on high RAS pumping rates (75 to 100%)
- Higher RAS rates will increase solids loading on final clarifiers
- Solids loading rate on clarifiers should not exceed 30 lb/(day-ft^2) at average loading
- Solids loading rate on clarifiers should not exceed 50 lb/(day-ft^2) at peak loading

Case Study: Wetumpka WWTP

Extended Aeration Activated Sludge

Design flow rate = 4.5 mgd (ave)

Actual flow rate = 1.5 mgd (ave)

Two 3.4 mil gal aeration tanks (both in service before)

Aeration & mixing hp (before change) = 7200 hp-hr/day

Now operate one aeration basin

Aeration & mixing hp (after change) = 5500 hp-hr/day

Energy savings = 460,000 kWh/yr = $70,000/yr

Reduction in energy use = 24%

Effluent Total N reduction = 62%

Case Study: Monroeville Double Branch WWTP

Oxidation Ditch Activated Sludge

Design flow rate = 1.0 mgd (ave)

Actual flow rate = 0.64 mgd (ave)

Two 0.5 mil gal oxid. ditches (both in service before)

Aeration hp (before change) = 1250 hp-hr/day

Now operate two oxid. ditches

Aeration hp (after change) = 1050 hp-hr/day

Energy savings = 46,000 kWh/yr = $5,200/yr

Reduction in energy use = 10%

Effluent Total N reduction = 56%

Case Study: Church Hill, TN WWTP

Oxidation Ditch Activated Sludge

Design flow rate = 2.5 mgd (ave)

Actual flow rate = 0.53 mgd (ave)

One 2.5 mil gal oxidation ditch

Aeration hp (before change) = 2400 hp-hr/day

Aeration hp (after change) = 1500 hp-hr/day

Energy savings = 220,000 kWh/yr = $20,000/yr

Reduction in energy use = 35%

Effluent Total N reduction = ?%

Case Study: Pell City WWTP

Oxidation Ditch Activated Sludge

Design flow rate = 4.75 mgd (ave)

Actual flow rate = 2.2 mgd (ave)

One 2.0 mil gal oxidation ditch

Aeration hp (before change) = 3600 hp-hr/day

Aeration hp (after change) = 2100 hp-hr/day

Energy savings = 350,000 kWh/yr = $34,000/yr

Reduction in energy use = 24%

Effluent Total N reduction = 65%

Troubleshooting

Troubleshooting Activated Sludge with N Removal

Nitrite Formation:

- Nitrite is formed during first step of nitrification
- Conversion of nitrite to nitrate may not occur because of:
  - low DO
  - low SRT
  - presence of inhibitory substance
  - other changes in influent ww char'tics
- High effluent nitrite levels result in high chlorine use

Troubleshooting Activated Sludge with N Removal

Nitrite Formation:

- May cause violation of ammonia or total N stds
- First indication of high level of nitrite in effluent is increase in chlorine demand
- When this happens, operator should immediately check effluent nitrite levels
- To correct problem,
  - get DO $\geq$ 2 mg/L
  - get SRT in normal operating range
  - lab analysis of inhibitory substances

Troubleshooting Activated Sludge with N Removal

Low pH:

- Optimum operating range for nitrification is 7.0 to 7.5
- Add sufficient alkalinity to maintain proper pH
- EXAMPLE

Influent ammonia-N conc	=	20 mg/L
Influent alkalinity	=	130 mg/L
Flow	=	10 mgd

Example of Alkalinity Calculations

Calculate amount of alkalinity required:

20 mg/L x 7.1 = 142 mg/L $CaCO_3$ required

Alkalinity for optimum pH =

142 mg/L + 50 mg/L (residual alk) = 192 mg/L

Alkalinity needed = 192 - 130 = 62 mg/L

Alk req'd = 10 mgd x 8.34 x 62 mg/L = 5171 lb/day (without denitrification)

Troubleshooting Activated Sludge with N Removal

Nocardia:

- *Nocardia* produce a brown, viscous foam that floats on surface of aeration tanks and clarifiers
- Enhanced *nocardia* growth is usually associated with high SRTs (> 6 days)
- High foam production may occur when operating a denitrification process
- *Nocardia* may be controlled by chlorinating RAS (7 to 9 mg/L) for up to 72 hours

Troubleshooting Activated Sludge with N Removal

Nocardia (continued):

- Should not affect nitrifying/denitrifying bacteria or organisms associated with BOD removal
- Do microbial exam daily to observe any adverse changes to microbial population
- Increased effluent turbidity also signals problems → stop chlorination of RAS immediately
- May get better control of *nocardia* by chlorine spray directly onto aeration tank surface

Troubleshooting Activated Sludge with N Removal

Observation: BOD < 25 mg/L NH_3-N > 3 mg/L

Solution:

Ensure SRT is sufficient for operating temperature

Observation: NH_3-N = erratic, > 3 mg/L and < 2 mg/L in short time period

Solution:

Waste sludge operation not stabilized; stop wasting until NH_3-N < 2 mg/L for 3 consecutive days; restart a careful sludge wasting program

Troubleshooting Activated Sludge with N Removal

Observation: Dark brown or black MLSS

NH_3-N > 3 mg/L

Solution:

Check aeration zone DO, should be ≥ 2 mg/L; check MLSS solids balance; SRT may be too high

Troubleshooting Activated Sludge with N Removal

Observation: Brown clumps of sludge floating on final clarifier surface

eff NH_4-N < 2 mg/L BOD < 30 mg/L

Solution:

N_2 gas bubbles being produced in stagnant sludge in clarifier; increase return sludge recycle rate; increase frequency of cleaning of clarifier walls and weirs

Troubleshooting Activated Sludge with N Removal

Observation: Eff NH_4-N > 10 mg/L BOD > 25 mg/L

Solution:

Check SRT, mixed liquor DO, and MLSS; if all are satisfactory, plant may be receiving inhibitory chemical; check pretreatment program

Troubleshooting Activated Sludge with N Removal

Observation: Eff NO_3-N > 7 mg/L NH_4-N < 2 mg/L

Solution:

DO in anoxic zone, should be less than 0.2 mg/L